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Geochemistry of Compositionally Distinct Late Cretaceous Back-Arc Basin Lavas: Implications for the Tectonomagmatic Evolution of the Caribbean Plate

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ABSTRACT

The Cretaceous Blue Mountain Inlier of eastern Jamaica contains the Bellevue lavas, which represent a Mid- to Late Campanian back-arc basin succession of tholeiitic volcanic rocks. The lavas are composed of basic/intermediate and intermediate/acidic subgroups that can be related by intraformation fractional crystallization. Trace element and Hf radiogenic isotope data reveal that the mantle component of the Bellevue magmas is consistent with derivation from a mantle plume (oceanic plateau) source region. Modeling indicates that the magmas formed by 10%–20% partial melting of an oceanic plateau mantle source comprising spinel peridotite that had previously undergone approximately 5%–7.5% prior melt extraction in the garnet stability field. Trace element and radiogenic isotope systematics suggest that the Bellevue mantle source region was contaminated with a slab-derived component from both the altered basaltic slab and its pelagic sedimentary veneer. The data from the Bellevue lavas support the plateau reversal model of Caribbean tectonic evolution, whereby subduction on the Great Arc of the Caribbean was to the northeast until the Caribbean oceanic plateau collided with the southern portion of the Great Arc in the Santonian (85.8–83.5 Ma), resulting in subduction polarity reversal and thus southwest-dipping subduction. This polarity reversal allowed oceanic plateau source regions to be melted beneath a new back-arc basin to the southwest of the Great Arc.

Online enhancement: appendix table.

Introduction

The Caribbean plate has active subduction zones on the eastern and western margins, with the Cocos plate subducting under Central America to produce the Costa Rica and Panama arc and Atlantic oceanic crust subducting in a westerly direction to form the active Lesser Antilles island arc (fig. 1). In contrast, the northern and southern boundaries of the plate are complex areas of strike-slip motion and rifting, with sinistral strike-slip motion along the northern boundary and dextral motion along the southern boundary (fig. 1).

It is now almost universally accepted that the Caribbean plate is predominantly composed of an ~90-Ma Pacific-derived oceanic plateau that was erupted onto Farallon oceanic crust and has been tectonically emplaced between North and South America since the Mid- to Late Cretaceous (e.g., Duncan and Hargraves 1984; Burke 1988; Kerr et al. 1999, 2003; Pindell et al. 2006; Pindell and Kennan 2009; Hastie and Kerr 2010).

A subduction polarity reversal of a Cretaceous island arc in-between the Americas from northeast dipping to southwest dipping combined with sub-

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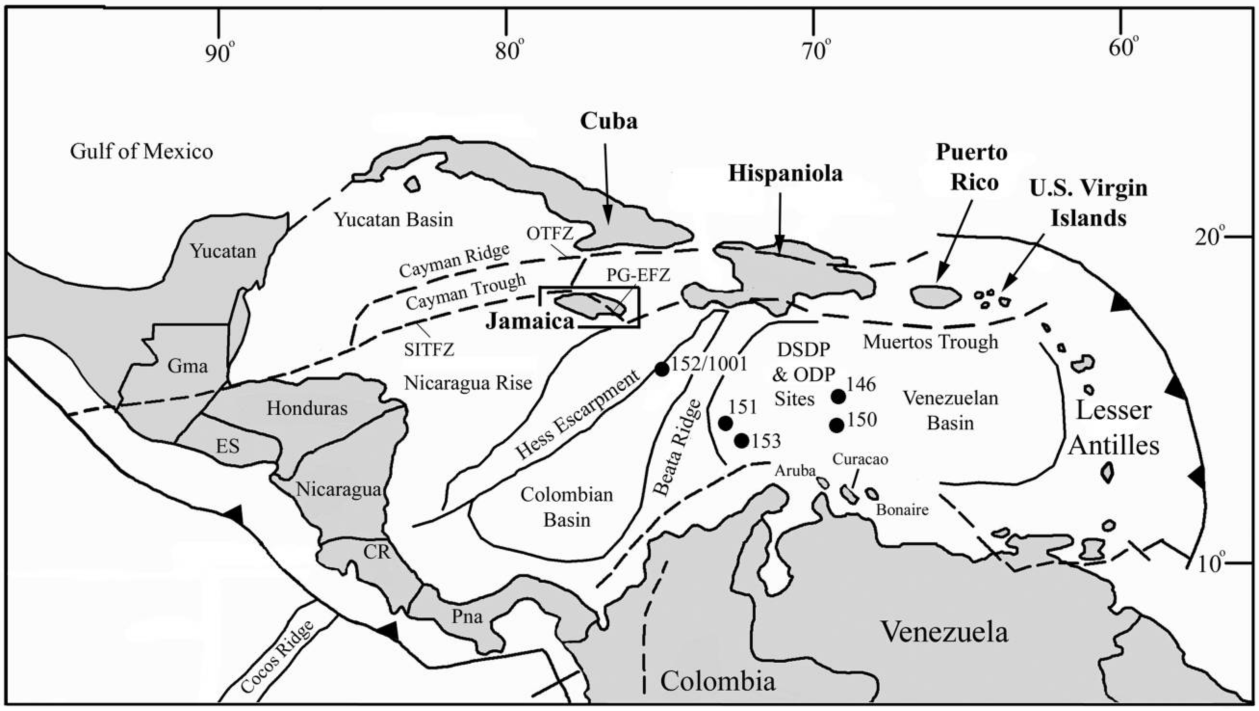


Figure 1. Map of the Caribbean and Central American region (modified from Sinton et al. 1998). *Gma*, Guatemala; *ES*, El Salvador; *CR*, Costa Rica; *Pna*, Panama; *SITFZ*, Swan Islands transform fault zone; *OTFZ*, Oriente transform fault zone; *PG-EFZ*, Plantain Garden–Enriquillo fault zone; *DSDP*, Deep Sea Drilling Project; *ODP*, Ocean Drilling Program.

sequent subduction back step, and the development of strike-slip faulting on the northern and southern Caribbean plate margins were the mechanisms responsible for isolating the Caribbean as a separate plate (e.g., Duncan and Hargraves 1984; Burke 1988; Lebron and Perfit 1993, 1994; Schellekens 1998; Diebold et al. 1999; Kerr et al. 1999, 2003; Müller et al. 1999).

However, despite the consensus on the Pacific origin of the Caribbean plate, the timing and mechanisms responsible for the subduction polarity reversal are still controversial. Some studies (e.g., Lebron and Perfit 1993, 1994; Pindell and Kennan 2001, 2009; Kesler et al. 2005; Jolly et al. 2006; Pindell et al. 2006; Escuder Viruete et al. 2007; Marchesi et al. 2007) propose an Aptian/Albian (125–99.6 Ma or older) reversal because of accelerated Atlantic sea floor spreading at this time (fig. 2). Conversely, others (e.g., Burke 1988; Schellekens 1998; Sinton et al. 1998; Kerr et al. 1999, 2003; White et al. 1999; Thompson et al. 2003; Mann et al. 2007; Hastie and Kerr 2010; Hastie et al. 2010) argue for a Turonian-Santonian (93.5–83.5 Ma) reversal, which is related to the collision of the Caribbean oceanic plateau with the inter-American arc (fig. 2).

In this article, we present the geochemistry of Middle to Late Campanian (~75 Ma) back-arc basin lavas from eastern Jamaica. The geochemistry and age of these lavas suggest that the Caribbean oceanic plateau was located close to and had a compositional effect on the Great Arc of the Caribbean in the Late Cretaceous. As we will discuss, this significant finding has fundamental implications for our understanding of Caribbean plate evolution models.

Jamaican Geology: The Blue Mountain Inlier

The Blue Mountain Inlier (fig. 3*a*) represents the largest area of Cretaceous rocks in Jamaica (Krijnen and Lee Chin 1978). Its rugged topography, however, makes geological investigations difficult, and despite various studies (Krijnen and Lee Chin 1978; Draper 1986; Krijnen et al. 1993; Montgomery and Pessagno 1999; Ramsook 2008; Mitchell and Ramsook 2009), the inlier is still poorly understood. The inlier contains three suites of contrasting rocks that

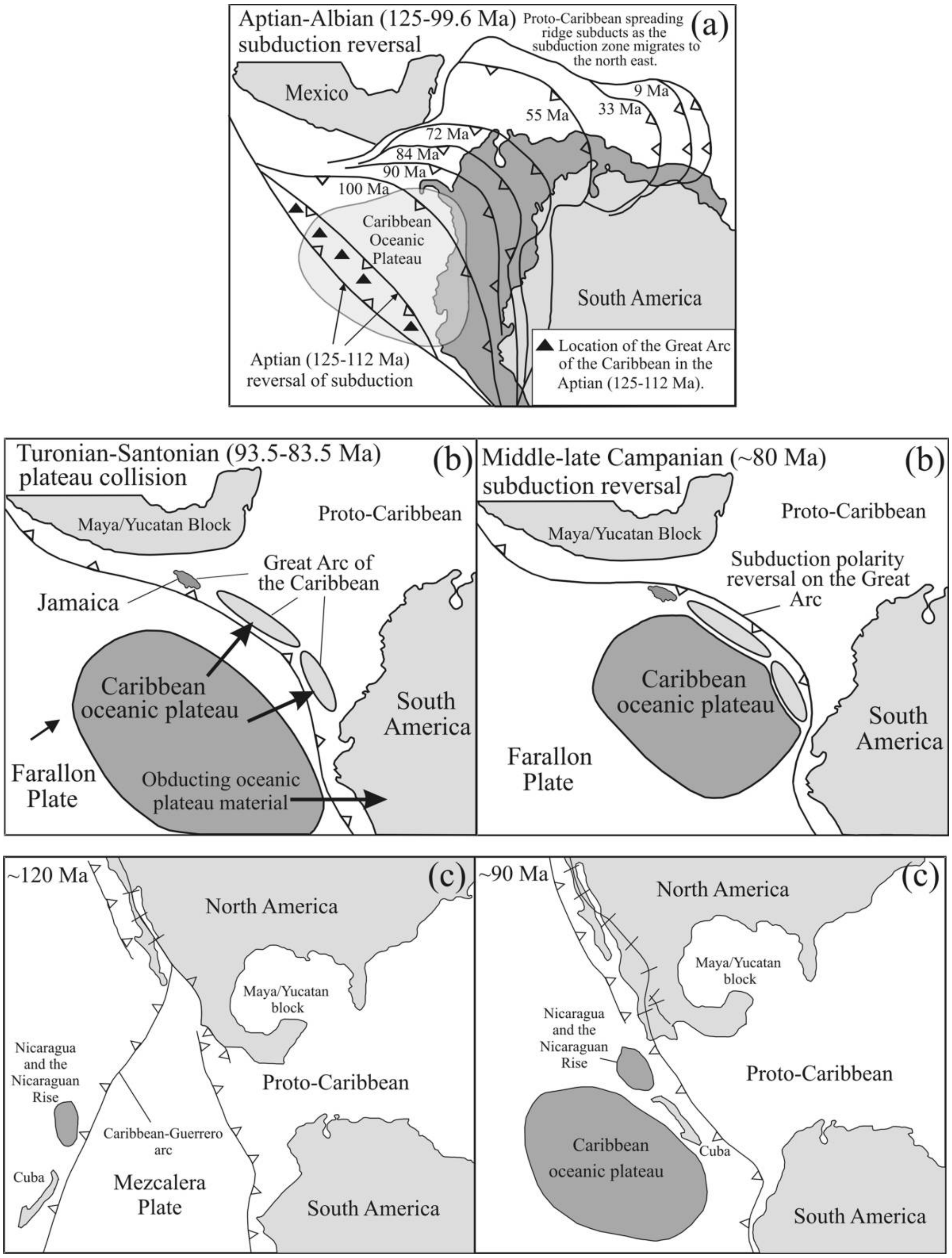


Figure 2. Illustrations showing the evolution of the Caribbean plate from the Mid- to Late Cretaceous based on the tectonic models of (*a*) Pindell et al. (2006), (*b*) Kerr et al. (1999) and Hastie et al. (2010), and (*c*) Mann et al. (2007). Dark gray shading in South America in *a* represents the location of the continent at ~120 Ma.

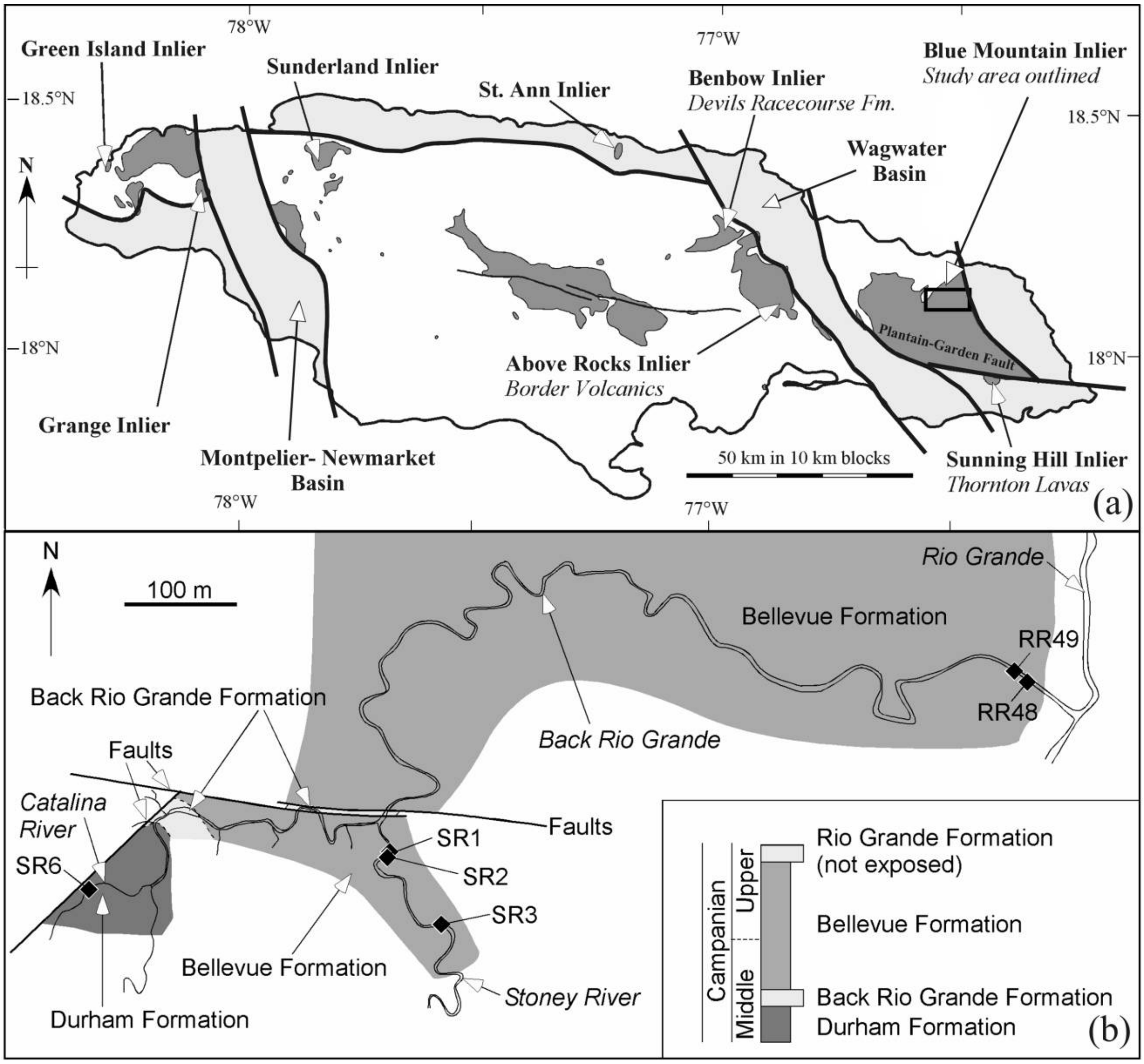


Figure 3. *a*, Map of Jamaica showing the location of the Blue Mountain Inlier. *b*, Map of the study area showing (1) the location of the Durham and Bellevue formations and (2) where the samples were collected (modified from Mitchell and Ramsook 2009).

are separated by regional-scale faults. The southwestern portion of the inlier consists of a suite of metamorphic rocks and minor serpentinites faulted against lavas. The metamorphic rocks include blueschists and amphibolites (Draper 1986; Abbott et al. 1996, 2003), but the ages of the protolith(s) and the metamorphic event(s) are poorly constrained. The southeastern portion of the inlier consists of a suite of basalts, the Bath-Dunrobin Formation, overlain by a thick deepwater sedimentary succession, the Cross Pass Shales (Krijnen and Lee Chin 1978). The Bath-Dunrobin lavas comprise Late Turonian–Early Coniacian basaltic lavas that are considered to represent part of the Caribbean oceanic plateau (Hastie et al. 2008). The northern part of the inlier is represented by a suite of volcanic rocks interbedded with volcaniclastic sediments and thin limestones, and it is these rocks that are the subject of this article (fig. 3*b*).

The geology of the northeastern part of the Blue

Mountains is presented by Mitchell and Ramsook (2009; fig. 3*b*). The oldest exposed rocks are lavas and brecciated lavas, which McFarlane (1977) termed the Durham Formation. These are succeeded by the Back Rio Grande Formation, a unit of thin limestones interbedded with volcaniclastic deposits (sandstones and conglomerates; Mitchell and Ramsook 2009). These limestones contain a diverse assemblage of rudist bivalves, including *Barrettia monilifera* Woodward and the larger foraminifer *Pseudorbitoides trechmanni* Douvillé (Krijnen et al. 1993; Mitchell and Ramsook 2009), which indicate a Mid-Campanian age (fig. 3*b*). The overlying ~600–1500-m-thick Bellevue Formation consists of a series of lava flows interbedded with minor volcaniclastic sediments and is succeeded by a rudist-bearing limestone unit, the Rio Grande Formation (e.g., Krijnen and Lee Chin 1978). The Rio Grande Formation contains a suite of rudists and larger foraminifers of Late Campanian age (Mitchell and Ramsook 2009; fig. 3*b*).

Field Locations and Petrography

Samples were collected from fresh outcrops of the Durham and Bellevue formations exposed in the Catalina River, the Stoney River, and the Back Rio Grande (fig. 3*b*). Sample S6 is the oldest and comes from the Durham Formation of Early or Early Mid-Campanian age. Samples SR01-03 (lower Bellevue Formation) and RR48-49 (upper Bellevue Formation) are age constrained by the Back Rio Grande and Rio Grande formations placing them in the Late Middle or Early Late Campanian (fig. 3*b*). Additionally, although SR06 is from the Durham Formation, in the interests of clarity, the rocks are collectively referred to as the Bellevue lavas in this article.

The lavas are porphyritic in thin section and are predominantly composed of plagioclase and clinopyroxene phenocrysts in a groundmass of plagioclase, clinopyroxene, and Fe-Ti oxides. The primary mineralogy of the lavas has been variably altered to clay minerals, sericite, and chlorite with occasional calcite veins.

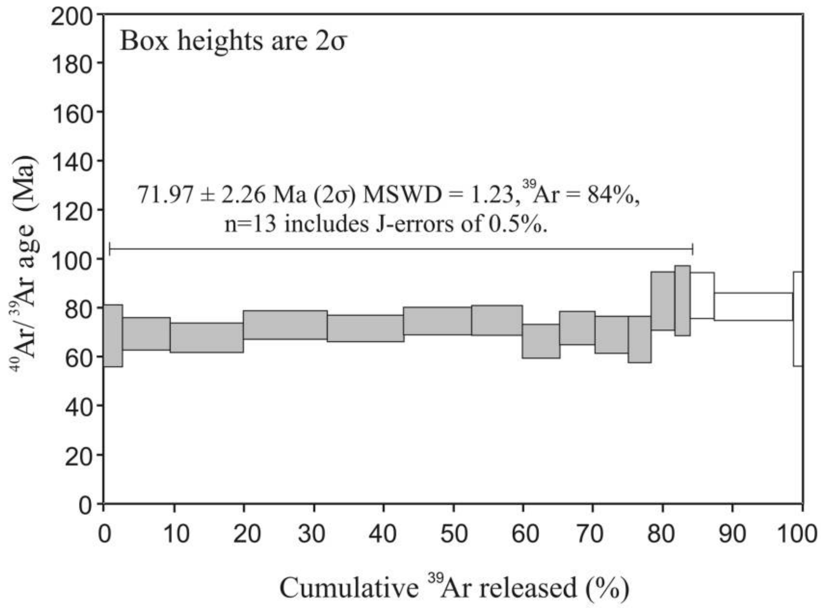
$^{40}Ar/^{39}Ar$ Geochronology

Analytical Techniques. Following removal of altered zones from sample SR01, the rock was crushed and sieved and plagioclase crystals (100–300 μm) were collected using magnetic separation. The separate was subsequently cleaned in dilute HNO_3, HF, and deionized water. Plagioclase crystals were handpicked to remove altered grains. The sample was loaded into a Cu packet, placed into a quartz vial, and then positioned in an Al can for irradiation. Al packets of Fish Canyon Tuff sanidine (28.02 ± 0.16 Ma, 1σ; Renne et al. 1998) were placed adjacent to samples to permit characterization of the irradiation flux to the samples. The sample was irradiated (unlined) in the McMaster reactor for 4 h.

The sample was step heated for 5 min in a fully automated, all-metal, double-vacuum, resistively heated furnace over a temperature range from 500° to 1750°C. Extracted gases were cleaned for 10 min using 3 SAES GP50 getters (two operated at 450°C and one at room temperature). Data were collected using a fully automated ARGUS multicollector noble mass spectrometer at the Natural Environment Research Council Argon Isotope Facility, Scottish Universities Environmental Research Centre, East Kilbride (Mark et al. 2009).

ArArCalc was used to regress data and calculate ages (Koppers 2002). Isotope data were corrected for blanks, radioactive decay, mass discrimination, and interfering reactions. $^{40}Ar/^{39}Ar$ ages also include a 0.5% error assigned to the J-parameter. Raw data, correction factors, and the J-parameters are available as an Excel file in the online edition or from the *Journal of Geology* office. The criterion for fitting of plateaus is that they must include at least 60% of ^{39}Ar in three or more contiguous steps. There is no resolvable slope on the plateau or any outliers or trends at upper or lower steps. The probability of fit of plateau to the data is >0.05 (fig. 4).

Results. The full raw data are presented in the Excel file. The $^{40}Ar/^{39}Ar$ data yield a concordant age spectrum with a plateau age of 71.97 ± 2.26 Ma (2σ; fig. 4). The slightly high MSWD for the plateau (1.23) is below the accepted cutoff value of 2 and is related to poor sample quality. Low radiogenic ^{40}Ar yields are typical of highly altered low-potassium plagioclase separates and are a feature of our data (maximum yield of 61% radiogenic ^{40}Ar; Excel file), responsible for the slightly elevated MSWD and large uncertainty associated with the $^{40}Ar/^{39}Ar$ plateau age (±3%, 2σ). The inverse isochron (fig. 4) suggests that some steps show evidence of excess Ar (Ar_E; Kelley 2002). These steps were rejected to bring the $^{40}Ar/^{36}Ar$ within accepted air values (Nier 1950). The same steps were rejected from the age spectrum. The inverse isochron age (75.38 ± 5.32 Ma, 2σ), plateau age (71.97 ± 2.26 Ma, 2σ), normal isochron age (71.13 ± 5.46 Ma, 2σ), and total fusion age (72.68 ± 1.95 Ma, 2σ) all overlap at the 2σ level, indicating the $^{40}Ar/^{39}Ar$ data to be robust (Excel file)



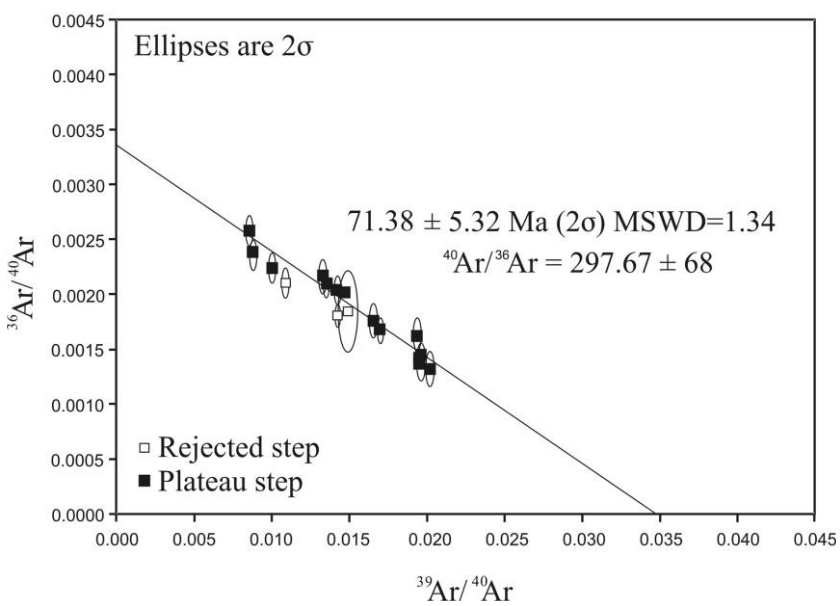


Figure 4. Inverse isochron and plateau diagrams for a plagioclase split from sample SR01. Full analytical procedures can be found in the text. For the inverse isochron diagram, the data point error ellipses are 2σ. For the plateau diagrams, the box heights are 2σ.

and that the dates support the paleontological ages from the Back Rio Grande and Rio Grande formations.

Geochemical Results

Analytical Techniques. Major and trace element data were analyzed using a JY Horiba Ultima 2 inductively coupled plasma optical emission spectrometer (ICP-OES) and a Thermo X7 series inductively coupled plasma mass spectrometer (ICP-MS) at Cardiff University (table A1, available in the online edition or from the *Journal of Geology* office). A full description of the analytical procedures and equipment at Cardiff University can be found in the study by McDonald and Viljoen (2006). Multiple analyses of international reference materials JB-1a, BIR-1, W2, JA-2, MRG-1, and JG-3 and four in-house standards ensured the accuracy and precision of the analyses. Most elements did not deviate more than 5% from standard values and have first relative standard deviations below 5% (for JB-1a data, see table A1).

Nd and Hf isotope compositions were analyzed at the Natural Environment Research Council Isotope Geoscience Laboratories, Nottingham. For Hf isotope analysis, the samples were prepared following the procedures of Münker et al. (2001) and run on a Nu-Plasma multicollector ICP-MS. Determinations of Nd isotopes followed the procedures of Kempton (1995) and Royse et al. (1998). Nd was run as the metal species using double Re-Ta filaments on a Finnigan Triton mass spectrometer (table 1).

Alteration and Fractional Crystallization. Studies on altered Cretaceous igneous rocks in the Caribbean have shown that most large-ion lithophile elements (LILE) have been variably mobilized by a range of weathering, hydrothermal, and metamorphic processes (e.g., Révillon et al. 2002; Thompson et al. 2003; Escuder Viruete et al. 2007; Hastie et al. 2007, 2008). Assessing the mobility of incompatible elements in an altered suite of lavas often relies on studying the intraformation differentiation patterns on Harker bivariate variation diagrams (e.g., Cann 1970). An immobile element (usually Nb) is plotted on the horizontal axis, and elements to be evaluated are plotted on the vertical axes. If the two elements are moderately to highly incompatible and immobile and the samples are cogenetic, the data should give trends with slopes close to unity (Cann 1970; Hill et al. 2000; Kurtz et al. 2000).

Hastie et al. (2007, 2008) have shown that several elements (e.g., K, Ba, U, and Sr) in the Early to Middle Cretaceous island arc and oceanic plateau rocks of Jamaica have been mobilized by subsolidus alteration processes and cannot be used for petrogenetic interpretations. This is also the case for the Bellevue lavas in this study. In figure 5, K_2O and Sr are shown as examples of elements of low ionic potential, which when plotted against Nb exhibit a large scatter with little evidence of the expected, prealteration slope of unity. Therefore, K and Sr (and other low-ionic-potential elements) have been mobilized during posteruptive hydrothermal and weathering processes and so cannot be used to study the petrogenesis of the Bellevue lavas.

In contrast, the immobile elements—for example, Zr, La, Sm, and Yb—give linear trends with a slope of unity when plotted against Nb, indicating that the elements are relatively immobile and that the variations may be explained by intraformation differentiation. Consequently, figure 5 shows fractional crystallization vectors for the immobile elements (partition coefficients taken from Rollinson 1993) and demonstrates that the most primitive Bellevue lava can be related to the most evolved samples by the crystallization of variable amounts of olivine, plagioclase, and clinopyroxene.

Trace Element Composition. On the Th-Co discrimination diagram of Hastie et al. (2007), the Bellevue lavas plot in the island arc tholeiite (IAT) field (fig. 6) as two distinct groups: (1) a basic/intermediate subgroup with basaltic/basaltic andesite compositions and (2) an intermediate/acidic subgroup with andesitic/dacitic compositions. The former subgroup has the lower incompatible element concentrations on the Harker variation diagrams (fig. 5).

On a normal mid-ocean ridge basalt (N-MORB)–normalized multielement diagram, the Bellevue lavas have slightly depleted Y and heavy rare earth element (HREE) abundances and enriched LILE and light rare earth element (LREE) concentrations (fig. 7*a*). The high-field-strength element (HFSE) abundances are more complex with N-MORB-like Zr-Hf contents but more enriched Nb-Ta concentrations. The acidic subgroup is more fractionated with slightly higher LILE-LREE-Nb-Ta/Zr-Hf-HREE ratios than the basic subgroup (fig. 7). The acidic subgroup also has negative Ti anomalies as a result of fractionation of Fe-Ti oxides (fig. 7a).

The basic/intermediate Bellevue lavas have some trace element patterns similar to the Bath-Dunrobin oceanic plateau basalts that form discrete tectonic blocks in the southeast of the Blue Mountain Inlier (Hastie et al. 2008). However, the basic/intermediate Bellevue lavas are more enriched in Th and LREE relative to Zr, Hf, and the HREE than the oceanic plateau lavas, for example, average La/

Table 1. Nd-Hf Isotope Data for the Bellevue Lavas

		$^{176}Hf/^{177}Hf$				$^{143}Nd/^{144}Nd$		
	$^{176}Lu/^{177}Hf$	Measured	Initial	$\varepsilon_{Hf}(i)$	$^{147}Sm/^{144}Nd$	Measured	Initial	$\varepsilon_{Nd}(i)$
SR06	.0182	.28312	.28309	13.10	.161	.51297	.51289	6.85
RR48	.0221	.28313	.28309	13.23	.166	.51295	.51287	6.34

Note. The chondrite values used to calculate the ε_{Hf} and ε_{Nd} values are 0.28273 and 0.51256, respectively. Initial and ε values calculated using 75 Ma.

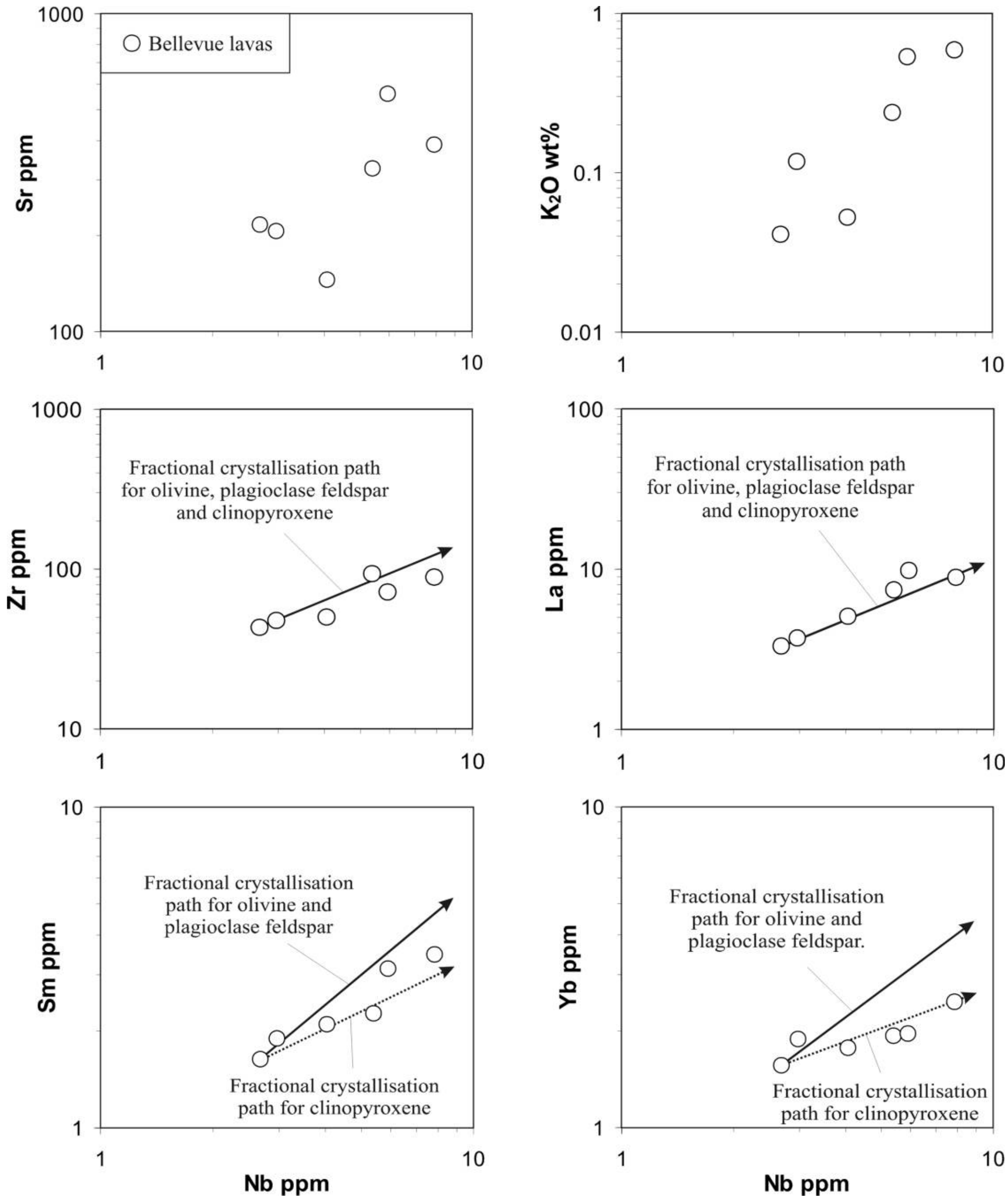


Figure 5. Selected variation diagrams for a range of elements plotted against the most immobile element, Nb. In all immobile trace element diagrams, variations within the Bellevue lavas are due to the fractional crystallization of olivine, plagioclase feldspar, and clinopyroxene.

Zr ratios 0.10 and 0.06 and average Th/Yb ratios 0.16 and 0.11 for the Bellevue and Bath-Dunrobin oceanic plateau lavas, respectively (fig. 7*c*). More importantly, the Bellevue lavas have more enriched Th and LREE concentrations relative to Nb and Ta when compared with the Bath-Dunrobin lavas, thus producing a slightly negative Nb and Ta anomaly on the multielement diagram in figure 7*a*. This anomaly can be quantified using N-MORB-normalized $(Th/Nb)_{n\text{-}mn}$ and $(La/Nb)_{n\text{-}mn}$ ratios, where the average values range from 2.2 to 1.4 and from 1.2 to 1.0 for the Bellevue and oceanic plateau rocks, respectively (fig. 7*c*). The lack of evidence for continental crust beneath Jamaica (e.g., Rob-

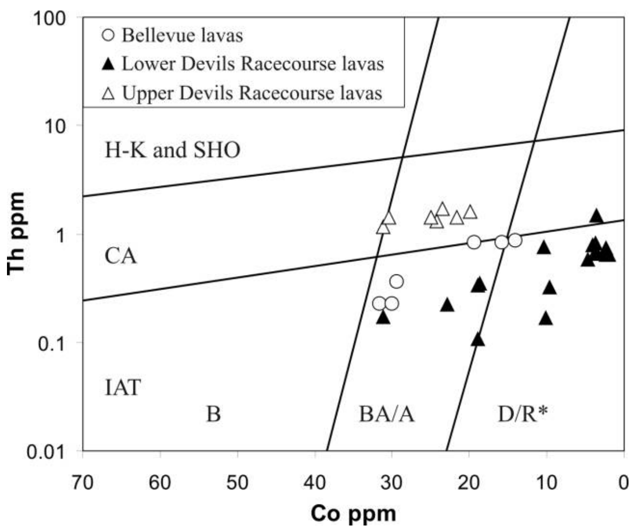


Figure 6. Th-Co classification of the Bellevue lavas. *IAT*, island arc tholeiite; *CA*, calc-alkaline; *H-K and SHO*, high-K calc-alkaline and shoshonite; *B*, basalt; *BA/A*, basaltic-andesite and andesite; *D/R**, dacite and rhyolite. Asterisk indicates that latites and trachytes also fall in the D/R fields. Th-Co diagram from Hastie et al. (2007), and Jamaican island arc–derived Devils Racecourse data from Hastie et al. (2009).

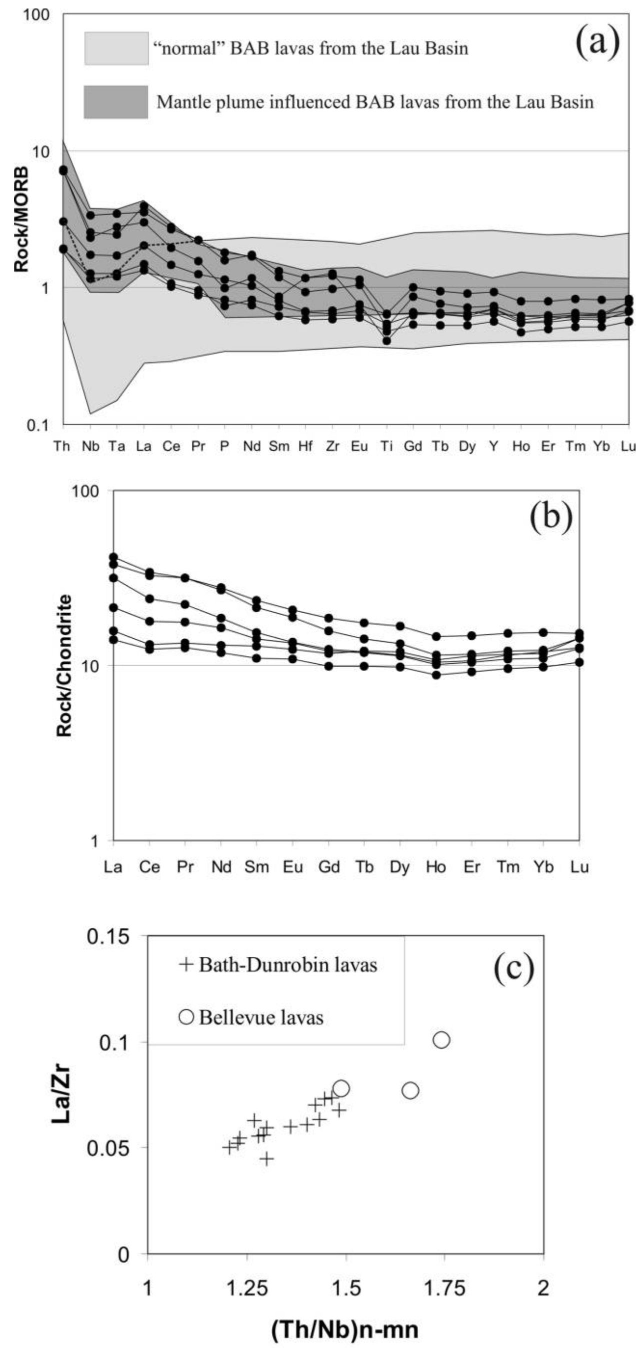


Figure 7. Normal mid-ocean ridge basalt–normalized multielement diagram (*a*) and chondrite-normalized rare earth element diagram (*b*). Data for the Lau Basin back-arc basin (*BAB*) lavas are derived from Ewart et al. (1994), Peate et al. (2001), Falloon et al. (2007), and Regelous et al. (2008). Normalizing values in *a* and *b* are from Sun and McDonough (1989) and McDonough and Sun (1995), respectively. *c*, La/Zr-$(Th/Nb)_{n\text{-}mn}$ diagram showing the basic/intermediate subgroup and the basalts of the oceanic plateau–derived Bath-Dunrobin Formation.

inson et al. 1972; Draper 1986; Kesler et al. 2005; Hastie 2009) means that it is unlikely that the negative Nb-Ta anomalies in the Bellevue lavas could have been caused by assimilation of continental crust and so strongly indicate that these rocks were generated in a subduction zone.

Furthermore, the chondrite-normalized REE diagram (fig. 7*b*) shows that the lavas have slightly negative Ce anomalies. Similar negative Ce anomalies are present in the Hauterivian (~135 Ma) basic IAT lavas of the Devils Racecourse Formation in the Benbow Inlier (fig. 3*a*; Hastie et al. 2009). The negative anomaly is quantified by using an N-MORB-normalized Ce/Ce* ratio, for example, $Ce/[(La - Pr)/2] + Pr$. Both the basic IAT Devils Racecourse lavas and the basic Bellevue subgroup have $(Ce/Ce^{*})_{n\text{-}mn}$ values ≤ 0.9. The chondrite-normalized REE diagram also shows that the Bellevue lavas have slight U-shaped patterns with depletions in the middle rare earth elements relative to the LREE and HREE. This is reflected in the Ho/Lu ratios, which in average N-MORB are ~2.2 (Sun and McDonough 1989) but are more depleted in the Bellevue lavas, with ratios <1.9.

Nd and Hf Radiogenic Isotopes. Radiogenic Nd and Hf isotope data for samples SR06 and RR48 are presented in figure 8 and table 1. Paleontology and

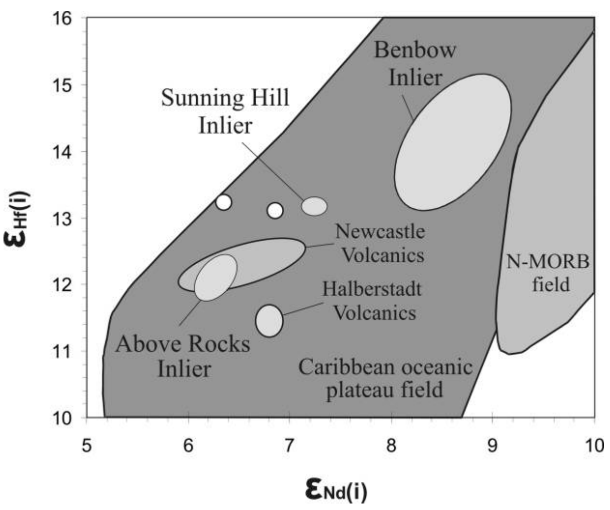


Figure 8. ε_{Nd}(i)-ε_{Hf}(i) diagram showing the Bellevue lavas relative to the island arc successions in Jamaica. Diagram modified from Hastie et al. (2010). *N-MORB*, normal mid-ocean ridge basalt.

the $^{40}Ar/^{39}Ar$ age indicates that the Bellevue lavas are Middle–Late Campanian in age; thus, the radiogenic isotopes have been age corrected to initial (i) values at 75 Ma. The Bellevue lavas possess ε_{Nd}(i) = +6.34 to +6.85 and ε_{Hf}(i) = +13.10 to +13.23 (fig. 8; table 1) and are distinct from the other island arc and oceanic plateau lavas in eastern Jamaica (e.g., Hastie et al. 2008; Hastie 2009), indicating that they are derived from a compositionally different source region.

Discussion

Overview of the Petrogenesis of Lavas within a Subduction Zone. Magmas generated beneath a volcanic arc represent complex partial melting of a peridotite mantle wedge that has been contaminated with aqueous and/or melt components derived from the subducting oceanic slab (e.g., McCulloch and Gamble 1991; Pearce and Parkinson 1993; Pearce and Peate 1995; Elliott 2003). Arc lavas, depending on the extent of melt depletion in the back-arc, commonly have N-MORB-like abundances of HFSEs (e.g., Nb, Ta, Zr, Hf, and Y) and HREEs and are relatively enriched in LILEs (e.g., K, Rb, and Ba), LREEs, and Th (e.g., Pearce 1982; McCulloch and Gamble 1991; Pearce and Peate 1995; Elliott 2003).

This enrichment in LILEs and LREEs relative to the HFSEs and HREEs is due to the addition of an aqueous slab-derived component into the mantle wedge (Pearce and Peate 1995; Elliott 2003). LILEs and LREEs are defined as nonconservative elements; that is, they are easily removed and transported by aqueous fluids and siliceous melts, thus concentrating them in any flux from the subducting slab (e.g., Tatsumi et al. 1986; Keppler 1996). In contrast, conservative elements, which include the HFSEs and the HREEs, remain in the slab as a result of the low solubility of minerals such as rutile, zircon, apatite, monazite, and garnet in the presence of aqueous fluids. Therefore, unlike the nonconservative elements, they are not concentrated into a slab-related aqueous fluid (Tatsumi et al. 1986; Keppler 1996). However, conservative elements can behave nonconservatively in the presence of a siliceous slab melt (Pearce and Peate 1995).

Therefore, two different slab components can be responsible for the enriched LILE and LREE composition of island arc magmas. These include (1) aqueous fluid from altered oceanic crust and sediment and (2) silicate melts from the oceanic basalt and sediment, which are transported from the subducting slab into the arc mantle wedge source region (e.g., Brenan et al. 1995; Turner and Hawkesworth 1997; Ishikawa and Tera 1999; Class et al. 2000; Elliott 2003).

Back-Arc Basin Lavas. Back-arc basins (BABs) and their associated active oceanic spreading ridges develop to the rear of an island arc because of extensional tectonics resulting from rollback of a subducting oceanic plate (e.g., Taylor and Martinez 2003). Examples of present-day BABs include the Lau Basin behind the Tongan Arc, the East Scotia Sea behind the South Sandwich Arc, and the Mariana Trough (e.g., Elliott et al. 1997; Turner and Hawkesworth 1998; Falloon et al. 2007; Regelous et al. 2008).

The lavas erupted at BAB spreading centers are geochemically heterogeneous, both within individual and between different BABs; nevertheless, BAB spreading ridge lavas that formed in proximity to the arc generally have arclike compositions, and rocks in the distal parts of the ridge have N-MORB-like compositions (e.g., Hawkins and Melchior 1985; Ewart et al. 1994; Pearce et al. 1995; Peate et al. 2001; Taylor and Martinez 2003; Pearce and Stern 2006; Regelous et al. 2008).

Distinguishing true MORB from the MORB-like lavas of a BAB spreading ridge is relatively simple because the MORB-like BAB rocks commonly still retain an "arclike signature," for example, slightly negative Nb and Ta anomalies on an N-MORB-normalized multielement diagram (e.g., Peate et al. 2001; Taylor and Martinez 2003). However, differentiating arclike BAB lavas from "normal" island arc lavas, based purely on geochemistry, is extremely difficult because they have similar geochemical signatures, for example, negative Nb and Ta anomalies and higher Sr isotope ratios relative to N-MORB.

Peate et al. (2001) and Taylor and Martinez (2003) have used major (Na and Fe) and trace element (U and Yb) systematics to link the decrease of a subduction component in BAB lavas to lower degrees of partial melting relative to volcanic arc lavas. Additionally, Pearce and Stern (2006) show that the subduction component of an island arc lava can be measured using a ratio of a nonconservative element to that of a conservative element and have shown that island arc lavas have higher Ba/Yb ratios than N-MORB. This works because Ba is preferentially added to the island arc magma source region in the slab-flux component. Interestingly, BAB lavas have intermediate Ba/Yb ratios that lie between N-MORB and island arc lava compositions (fig. 5; Pearce and Stern 2006). This is probably because the source region of BAB lavas is fluxed with volumetrically fewer slab-derived components than arclike source regions.

Are the Bellevue Lavas Derived from an Arc or Back-Arc Region? In general, the determination of the depositional setting of sedimentary successions within arc systems using stratigraphy and paleontology is problematic. The succession within the northeast Blue Mountains consists of a thick sequence of lavas interbedded with platform limestones with tropical shallow-water assemblages of rudist bivalves and larger foraminifers (fig. 3*b*). The stratigraphic and faunal data indicate that the deposits accumulated around an active volcanic center. Of particular note is the rudist assemblage from the Back Rio Grande Formation described by Mitchell and Ramsook (2009). The assemblage is rich in species but has only a single species in common (and even that has been only tentatively identified) with the diverse same-age rudist assemblages of the limestones of western Jamaica (Chubb 1971).

Since multiple depositional environments are represented in the western Jamaican exposures and the same larger benthic foraminifer assemblages are present in both areas, it is highly unlikely that the differences between the faunas are due to different depositional environments. Instead, we propose that western Jamaica and the northeast Blue Mountains were separated by sufficient distances, particularly regions of deep water, which prevented the dispersal of spat between the two regions. If the two areas, separated by only ~200 km at present, were on the same volcanic arc, it is unlikely that they would have had such different rudist assemblages. In contrast, if the northeast Blue Mountains formed in a distal back-arc setting, while western Jamaica was situated on the volcanic arc, then spat distribution may not have occurred across deep-water areas between the regions, resulting in the development of distinctive rudist assemblages in the back-arc region.

The Bellevue lavas represent a single part of the main back-arc region on the Great Arc of the Caribbean, which was geographically extensive (e.g., Pindell and Kennan 2009). The Bellevue rocks are the northern margin of the basin/extension and hence were never very deep. Deep-water Coniacian and Santonian shales are present to the south of the Bellevue lavas, and these represent the deep part of the BAB.

In addition, the Bellevue lavas are shown on a Th/Yb-Ta/Yb diagram of Pearce (1982) along with island arc lavas from the Benbow, Above Rocks, and Blue Mountain Cretaceous inliers (western Jamaica; fig. 9*a*). Similar to the Ba/Yb ratio study of Pearce and Stern (2006), the Bellevue lavas have Th/Yb ratios intermediate between the MORB array and a second array comprising Jamaican island arc lavas. This indicates that the subduction signature in the Bellevue lavas is not as pronounced as "normal" island arc rocks in the area, and this, combined with the stratigraphic and paleontological data, strongly suggests that the lavas are likely derived from a BAB.

The Affinity of the Mantle Source Region. Only "conservative" immobile trace elements, which are derived from the mantle and not from a subducting slab, can be used to study the mantle wedge component (Pearce and Parkinson 1993). However, as shown earlier, if the subduction component represents a siliceous slab melt, these conservative elements would behave nonconservatively. A siliceous melt from the subducting oceanic crust would have an adakitic composition (e.g., SiO_2 >56%, Al_2O_3 >15%, MgO <6%, low Y and HREE [Y and Yb <18 and 1.9 ppm, respectively], and high Sr [rarely <400 ppm]) or would eventually form a high-Mg andesite (e.g., high MgO, Cr, and Ni concentrations; Sr up to 3000 ppm; Ba >1000 ppm; and low FeO^*/MgO and high Na/K ratios), depending on the extent to which the melt hybridized with the peridotite in the mantle wedge (e.g., Saunders et al. 1987; Yogodzinski et al. 1995; Drummond et al. 1996).

The Bellevue lavas lack the characteristic compositional features of adakites and of high-Mg andesites; therefore, it is reasonable to assume that the slab component does not predominantly represent a siliceous melt and that the HFSE and HREE

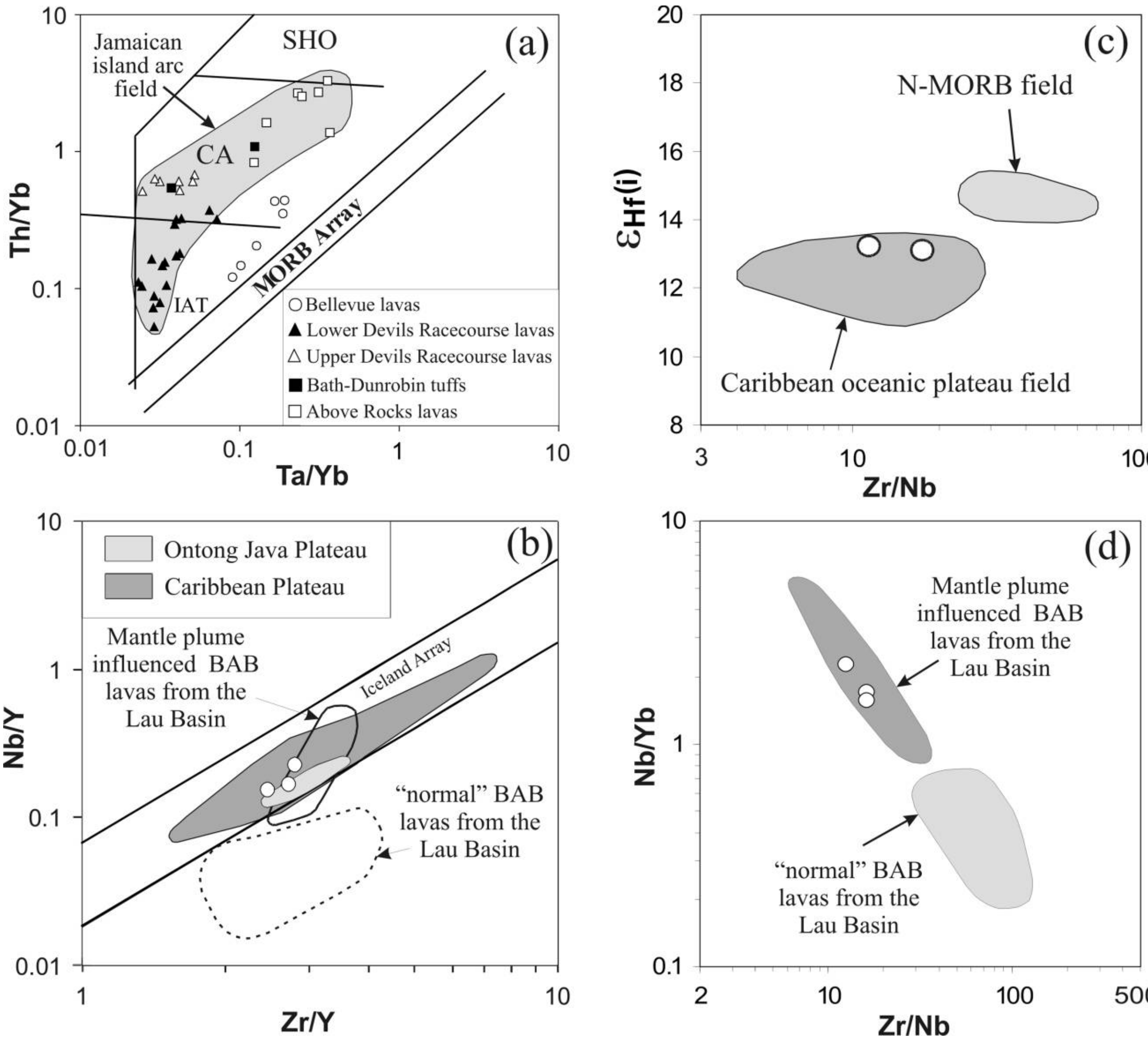


Figure 9. *a*, Th/Yb-Ta/Yb diagram of Pearce (1982), with the Bellevue lavas plotting between the Jamaican island arc field and the mid-ocean ridge basalt (*MORB*) array. *b*, Nb/Y-Zr/Y diagram from Fitton et al. (1997). The basic/intermediate subgroup of the Bellevue lavas plots in the Icelandic field with other lavas from the Caribbean oceanic plateau (diagram modified from Hastie et al. 2008). *c*, ε_{Hf}(i)-Zr/Nb plot modified from Kerr et al. (2009). *d*, Basic/intermediate subgroup plotted on a Nb/Yb-Zr/Nb diagram. Data for Lau Basin samples from Ewart et al. (1994), Peate et al. (2001), Falloon et al. (2007), and Regelous et al. (2008). *IAT*, island arc tholeiite; *CA*, calc-alkaline; *SHO*, shoshonite; *BAB*, back-arc basin.

can be used to determine the composition of the mantle wedge component involved in the genesis of the Bellevue magmas (e.g., Pearce and Parkinson 1993).

Figure 9*b* shows the basic/intermediate Bellevue lavas plotted on an Nb/Y-Zr/Y diagram (after Fitton et al. 1997). This diagram was originally constructed to distinguish between Icelandic plume lavas, which plot between two parallel tramlines, and N-MORB lavas that plot below the lower tramline (Fitton et al. 1997). In figure 9*b*, the basic/intermediate Bellevue lavas plot above the lower tramline, which implies that the mantle component involved in the petrogenesis of the back-arc lavas had a mantle plume composition.

Recently, Kerr et al. (2009) have used HFSE and HREE trace element and Hf radiogenic isotope systematics to evaluate the mantle source of depleted basalts from ODP Leg 165, site 1001 on the Hess Escarpment (fig. 1). They concluded that although the basalts were highly depleted in incompatible elements, the source region represented a depleted mantle plume source and not a depleted MORB mantle (DMM) source. If samples SR06 and RR48 are plotted on an ε_{Hf}(i)-Zr/Nb diagram (cf. Kerr et al. 2009), they fall in the Caribbean oceanic plateau field and are distinct from N-MORB samples from the East Pacific Rise (fig. 9*c*).

Both these lines of evidence (trace element and isotopic) suggest that the mantle wedge component involved in the genesis of the Bellevue magmas was similar in composition to the source region of mantle plume–derived magmas. It is therefore important to compare the Bellevue lavas with a present-day back-arc region, where the lavas have been derived from both a DMM and mantle plume–like mantle source.

Several BABs in the Pacific have source regions that have been "contaminated" by mantle plume material, with the most studied example being the Lau Basin. The composition of lavas in the northwestern section of the Lau Basin have been affected by the Samoan plume (e.g., Volpe et al. 1988; Wendt et al. 1997; Turner and Hawkesworth 1998; Peate et al. 2001; Falloon et al. 2007; Regelous et al. 2008).

Comparison of the Lau Basin BAB Lavas with the Blue Mountain BAB Lavas. The Lau BAB is located behind the Tongan Arc in the western Pacific (e.g., Ewart et al. 1994). The BAB lavas are heterogeneous and, like other BAB lavas, have compositions transitional between MORB and island arc (e.g., Pearce et al. 1995; Turner and Hawkesworth 1998; Peate et al. 2001). In the southern portion of the basin (the Valu Fa Ridge), the mantle wedge component has Pacific MORB compositions, the central basin (eastern Lau spreading center, intermediate Lau spreading center, and central Lau spreading center) has Indian MORB affinities, and the lavas in the north section of the basin (above 17°N; Niuafo'ou, northeastern Lau spreading center, King's/Mangatolo Triple Junction, Peggy Ridge, and Rochambeau Bank) have been contaminated by a Samoan mantle plume component (e.g., Volpe et al. 1988; Wendt et al. 1997; Turner and Hawkesworth 1998; Peate et al. 2001; Falloon et al. 2007; Regelous et al. 2008). Therefore, the transition from plume to MORB mantle components in the Lau BAB samples can be compared with the Jamaican BAB lavas to help determine the affinity of the mantle wedge component.

Tongan Arc and southern back-arc lavas are derived from an N-MORB mantle source region contaminated with a subduction fluid, which gives them Zr/Nb ratios of ~40–120, similar to global MORB values and Cretaceous island arc lavas on Jamaica (fig. 9*d*; Wendt et al. 1997; Hastie et al. 2009). However, lavas in the northern Tonga arc-back-arc region have much lower Zr/Nb ratios of ~16–21 relative to N-MORB (Wendt et al. 1997). Similarly, the basic Bellevue lavas have lower ratios of 12.4–16.1 (fig. 9*d*). Regelous et al. (2008), in a related study, show that Nb/Zr ratios in the Lau BAB basalts become progressively higher as one moves closer to the Samoan Islands.

Nb is more incompatible than Zr; therefore, the lower Zr/Nb (or higher Nb/Zr) ratios cannot be explained by previous partial melting events (e.g., Pearce and Stern 2006). Thus, given the moderate to high degrees of partial melting required to generate a BAB magma (10–20%; e.g., Pearce and Stern 2006), the more depleted Zr/Nb ratios in the northern Lau BAB and the Jamaican Bellevue lavas must be derived from a mantle source region more enriched in incompatible HFSEs (Nb and Ta) than DMM. Furthermore, in figures 7*a* and 9*b*–9*d*, the Bellevue BAB lavas plot in the field of mantle plume–influenced BAB lavas from the Lau Basin, and both sets of lavas have more enriched incompatible element values than the "normal" N-MORB-derived BAB lavas.

Partial Melt Modeling and the Nature of the Bellevue BAB Mantle Source Region. Although the basic Bellevue BAB lavas have ~6% MgO and so have undergone a considerable amount of fractionation, the use of incompatible trace element ratios enables us to "see through" effects of fractional crystallization and assess the composition of the mantle source region. Figure 10*a* shows calculated nonmodal batch partial melting curves for a DMM source (Workman and Hart 2005), an oceanic plateau source (Fitton and Godard 2004; Hastie and Kerr 2010), and residual oceanic plateau source regions that have previously undergone 15%, 20%, and 30% partial melting in the spinel peridotite stability field (e.g., Révillon et al. 2000; Hastie and Kerr 2010). Partition coefficients are from Pearce and Parkinson (1993), and mineral and melt modes are from Révillon et al. (2000).

The Bellevue lavas have higher Nb/Zr ratios than the partial melting curves for spinel peridotite (fig. 10*a*). It should be noted that, although extremely small (≤0.1%) degrees of partial melting of a refractory spinel peridotite source that has undergone a 30% prior depletion event can give similar compositions to the Bellevue lavas, this level of partial melting is unrealistic for BAB lavas because they generally form by 10%–20% partial melting (e.g., Pearce and Parkinson 1993; Pearce and Stern 2006).

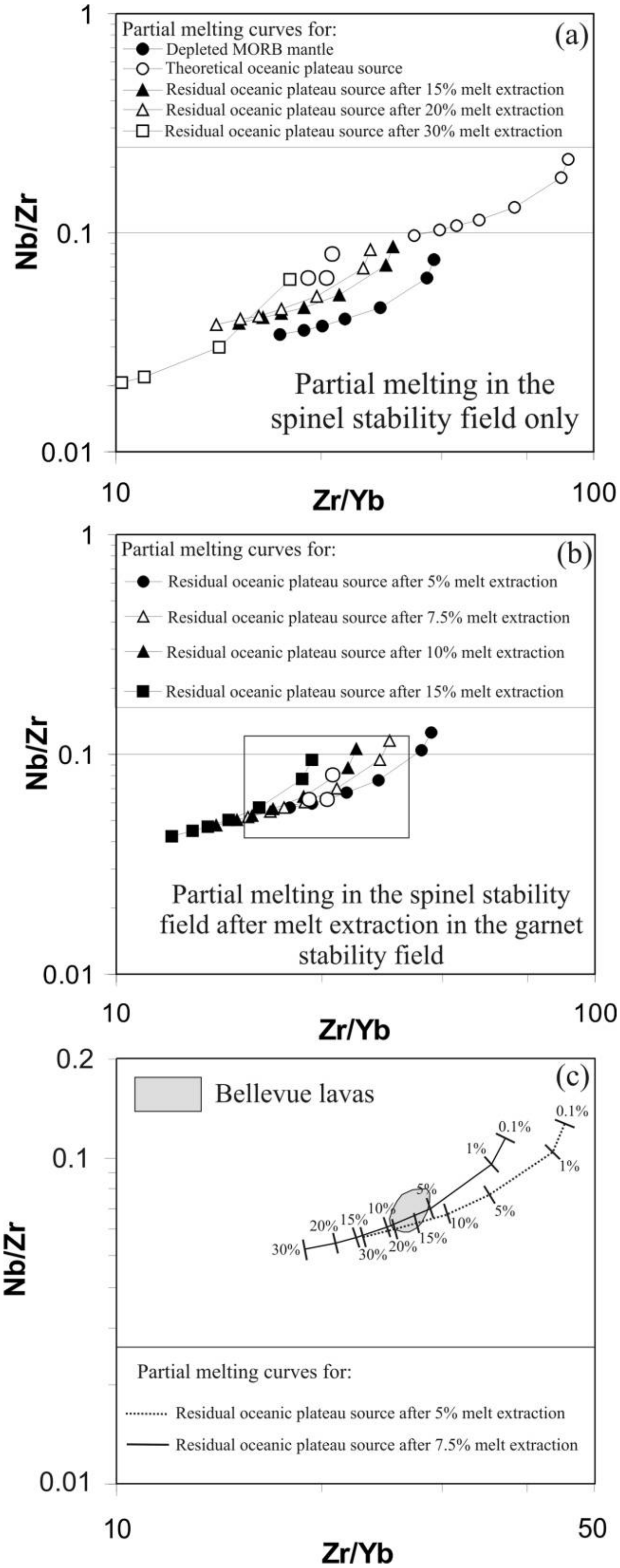


Figure 10. Nb/Zr-Zr/Yb plots showing modeled partial melts of depleted mid-ocean ridge basalt (*MORB*) mantle, an oceanic plateau source, and an oceanic plateau source depleted by melt extraction in the spinel and garnet stability fields. Mineral and melt modes and partition coefficients for the melting models are from Révillon et al. (2000) and Pearce and Parkinson (1993), respectively.

Also, small degrees of partial melting would give high Na concentrations when the values are corrected back to 8% MgO to take into account fractional crystallization (Na_8; e.g., Fretzdorff et al. 2002). The Bellevue lavas have Na_8 values from 1.4 to 2.8, thus ruling out small degrees of partial melting.

Conversely, in figure 10*b* and 10*c*, spinel peridotite partial melting curves for residual oceanic plateau source regions that have previously undergone partial melting in the garnet peridotite stability field are shown (Révillon et al. 2000). The Bellevue lavas plot on the partial melting curves for residual oceanic plateau source mantle that has previously undergone 5%–10% prior melt extraction. If it is assumed that back-arc lavas are formed from 10%–20% partial melting (e.g., Pearce and Stern 2006), the composition of the Bellevue lavas can be explained by 5%–10% partial melting of a spinel peridotite source previously depleted by 7.5% melt extraction in the garnet field or 10%–20% partial melting of a source previously depleted by 5% melt extraction (fig. 10*c*).

Previous melt extraction in the garnet stability field can also explain the slight U-shaped patterns in the chondrite-normalized REE plot in figure 7*b*. Partially melting DMM, oceanic plateau, and residual oceanic plateau source regions that have previously undergone variable partial melting in the spinel peridotite stability field produce melts with Ho/Lu ratios >1.9 that are higher than those of the Bellevue lavas (1.7–1.8). Nevertheless, a residual oceanic plateau source region that has previously undergone 5%–7.5% partial melting in the garnet peridotite stability field and that has subsequently undergone 10%–20% partial melting in a shallow BAB source region forms Ho/Lu ratios ranging from 1.6 to 1.8, thus explaining the U-shaped patterns. Interestingly, similar U-shaped patterns in oceanic plateau–derived rocks have recently been discovered from the Manihiki Plateau (Ingle et al. 2007). Ingle et al. (2007) also determined that the U-shaped patterns are derived from partially melting mantle that had previously undergone melt extraction in the garnet peridotite stability field.

Consequently, the HFSE and HREE trace element systematics and Hf isotopes demonstrate that the mantle component of the Bellevue BAB magmas was more enriched than an N-MORB source and is more likely to represent a mantle plume source region, composed of spinel peridotite that had previously undergone 5%–7.5% prior melt extraction in the garnet stability field.

Affinity of the Subduction Component. The slight negative Nb and Ta anomalies in figure 7*a*, the absence of continental crust beneath Jamaica (e.g., Robinson et al. 1972; Draper 1986; Kesler et al. 2005; Hastie 2009), and the lack of adakite/high Mg andesite compositions indicate that the mantle plume source region of the Bellevue lavas was contaminated by an aqueous fluid flux from a subducting slab. On a Th/Yb-Ta/Yb diagram, the Bellevue BAB lavas clearly plot above the MORB array but are not as enriched as the other Jamaican island arc lavas (fig. 9*a*). In addition, figure 8 also shows that the Bellevue lavas have different initial radiogenic isotope ratios to the other Jamaican arc rocks, indicating that they are derived from a compositionally different source region.

Figure 11 illustrates the likely affinity of the subduction component that was added to the mantle source region of the Blue Mountain lavas. The negative Ce anomaly ($[Ce/Ce^*]_{n\text{-}mn}$ ratios <1) in the Bellevue lavas suggests that the slab-related component was derived, at least in part, from pelagic sedimentary material (fig. 11). Negative Ce anomalies are associated with phosphate-rich phases in pelagic sediments and red clay sediments in oxidizing environments, and so the slab-related component has a negative Ce anomaly that subsequently imparts a negative Ce anomaly to the arc lavas (e.g., Ben Othman et al. 1989; McCulloch and Gamble 1991; Plank and Langmuir 1998; Elliott 2003). The Blue Mountain lavas also have Th/La ratios ≤0.1, which shows that the slab-related component was not derived from terrigenous sedimentary/upper continental crust material (Plank 2005).

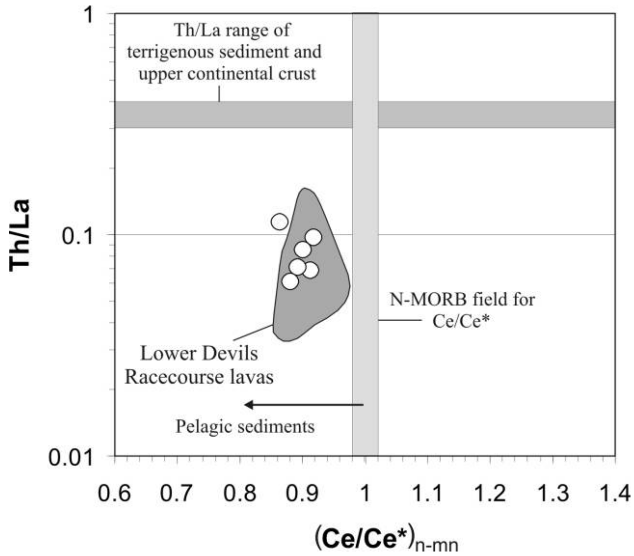


Figure 11. Th/La-$(Ce/Ce^*)_{n\text{-}mn}$ diagram from Hastie et al. (2009). $(Ce/Ce^*)_{n\text{-}mn}$ ratio is calculated by Ce/[(La − Pr)/2] + Pr. *N-MORB*, normal mid-ocean ridge basalt.

Significance of ~75-Ma Mantle Plume–Derived Back-Arc Lavas in the Northern Caribbean

Caribbean Tectonic Models. Three distinct models have been developed to explain the Cretaceous tectonomagmatic evolution of the Caribbean. The first model of Caribbean plate evolution is the Aptian/Albian reversal model (Pindell et al. 2006; Pindell and Kennan 2009), which proposes that as the American continents rifted apart to form the Proto-Caribbean ocean crust (fig. 2*a*), the inter-American Great Arc of the Caribbean (sensu Burke 1988) changed from a northeast-dipping into a southwest-dipping subduction zone by polarity reversal in the Aptian/Albian (fig. 2*a*). This polarity reversal resulted in the Proto-Caribbean spreading center being subducted to form a slab gap (fig. 2*a*). The Caribbean oceanic plateau subsequently erupted to the southwest of the Great Arc at ~90 Ma and was able to erupt close to the arc because the mantle plume that formed the plateau upwelled beneath the slab gap (Pindell et al. 2005, 2006; Pindell and Kennan 2009).

The main arguments for this model are (1) the geographic eastward location of Aptian (~120 Ma) high-pressure-low-temperature (HP-LT) rocks on the Greater Antilles islands (Pindell et al. 2006), (2) the change of island arc lava compositions in the Great Arc from tholeiitic (IAT) to calc-alkaline (CA; e.g., Kesler et al. 2005), and (3) an Aptian/Albian regional unconformity (occasionally associated with limestone platforms; e.g., Lebron and Perfit 1993, 1994; Pindell et al. 2006). Pindell et al. (2006) and Pindell and Kennan (2009) contend that the subduction polarity reversal may have taken place in the Aptian/Albian because of accelerated Atlantic sea-floor spreading (fig. 2*a*). However, in a note added in proof by Pindell and Kennan (2009), these authors suggest an earlier time (135 Ma) for southwest-dipping subduction initiation, without a flip at any time, because (1) the change from IAT to CA magmatism is not as distinct as once thought, (2) such an age predates all Caribbean subduction-related arc magmas and HP-LT metamorphic rocks such that they could have formed in one subduction system, and (3) pressure-temperature-time paths of HP-LT rocks in Cuba and Hispaniola are continuous and without interruption from the Early Cretaceous to the Eocene. Nevertheless, more information is required to fully assess the validity of this new model. As a consequence, we continue to use the published standard Aptian/Albian reversal model of Caribbean tectonic evolution, as proposed by Pindell et al. (2005, 2006) and Pindell and Kennan (2009).

In contrast to the Aptian/Albian reversal model, Duncan and Hargraves (1984) and Burke (1988; the plateau reversal model) and Mann et al. (2007; the multiple-arc model) favor a Turonian-Santonian subduction polarity reversal (fig. 2*b*, 2*c*). Kerr et al. (2003) and Hastie and Kerr (2010) have presented further evidence in support of the plateau reversal model, which suggests that most of the Caribbean plate consists of a Cretaceous oceanic plateau (~6 × 10^5 km^2) that formed in the Pacific realm at ~90 Ma by erupting onto the Farallon plate (possibly from the Galapagos hotspot [e.g., Thompson et al. 2003]). Hastie and Kerr (2010) and Hastie et al. (2010) further proposed that the Great Arc of the Caribbean must have been the site of a northeast-dipping subduction zone until ~80 Ma, when the Caribbean oceanic plateau collided with the Great Arc (fig. 2*b*; e.g., Duncan and Hargraves 1984; Burke 1988; Kerr et al. 2003). Unlike the Farallon oceanic crust, the Caribbean oceanic plateau would have been too thick, hot, and buoyant to completely subduct (e.g., Burke 1988; Saunders et al. 1996); as the plateau collided and accreted to the Great Arc, it "choked" the subduction zone and initiated subduction polarity reversal, whereby the proto-Caribbean crust began subducting in a southwesterly direction beneath the oceanic plateau (fig. 2*b*; e.g., Duncan and Hargraves 1984; Burke 1988; Kerr et al. 2003).

Mann et al. (2007) developed the multiple-arc model (fig. 2*c*), in which two subduction zones were active in the Caribbean/Pacific region in the Aptian/Albian. The Cuban and Jamaican portions of the Great Arc initially developed above a Pacific westerly-dipping subduction zone (the Caribbean-Guerrero arc) that was separated from a second northeast-dipping subduction zone between North and South America by the Mezcalera plate. Mann et al. (2007) suggest that the northeast-dipping subduction zone changed polarity at ~90 Ma because the Caribbean-Guerrero arc collided with the latter subduction zone as the Mezcalera plate was fully subducted (fig. 2*c*).

Refining the Current Models. The results of this study shed significant new light on the late Cretaceous tectonic evolution of the Caribbean plate. Hastie (2007, 2009) and Hastie et al. (2007, 2009) have previously shown that the older island arc lavas on Jamaica (>80 Ma) are derived from N-MORB-like source regions that have been contaminated by a subduction component, with no evidence to suggest the involvement of any mantle plume material.

In contrast, this study has shown that the Mid- to Late Campanian Bellevue lavas are derived from a subduction-modified oceanic plateau–type mantle source region. This discovery is therefore significant since it helps to constrain the timing of the contribution of mantle plume material to the source region of the island arc rocks that make up the Great Arc of the Caribbean. The Bellevue lavas indicate that mantle plume material—and, by inference, the Caribbean oceanic plateau—did not contribute to the source region of normal island arc volcanic rocks in the northern Great Arc until ~75 Ma.

Of the three Caribbean tectonic models, the Bellevue data are best explained by the plateau reversal model (fig. 2*b*). In this model, the Great Arc of the Caribbean developed above a northeast-dipping subduction zone from the early (<135 Ma) to the late (~80 Ma) Cretaceous. During this time, the Great Arc magmas were generated from subduction-modified N-MORB mantle source regions as the Farallon plate subducted and its slab flux modified Atlantic-type DMM (fig. 2*b*; e.g., Duncan and Hargraves 1984; Burke 1988; White et al. 1999; Thompson et al. 2003; Kerr et al. 2003; Hastie et al. 2009; Hastie and Kerr 2010). At 94–89 Ma, the Caribbean oceanic plateau erupted onto the Farallon plate in the Pacific and was transported to the northeast to collide with the Great Arc of the Caribbean (fig. 2*b*; e.g., Duncan and Hargraves 1984; Burke 1988; Kerr et al. 2003; Thompson et al. 2003; Hastie and Kerr 2010).

The exact timing of this collision is controversial because limited geochemical and geochronological data are available for the other islands of the Greater Antilles (e.g., Cuba and Puerto Rico), which would help to constrain the timing of any possible mantle plume involvement in the lavas of the Great Arc. However, the detailed geochemical and geochronological work on the Jamaican Bellevue rocks reveal that island arc lavas in the northern Great Arc show evidence of a mantle plume component from ~75 Ma (Hastie 2007, 2009; Hastie et al. 2007, 2009).

Figure 12 shows a series of illustrations that revise the plateau reversal model of Caribbean evolution in the northern Greater Antilles: before ~80 Ma, the Farallon plate subducted beneath the Proto-

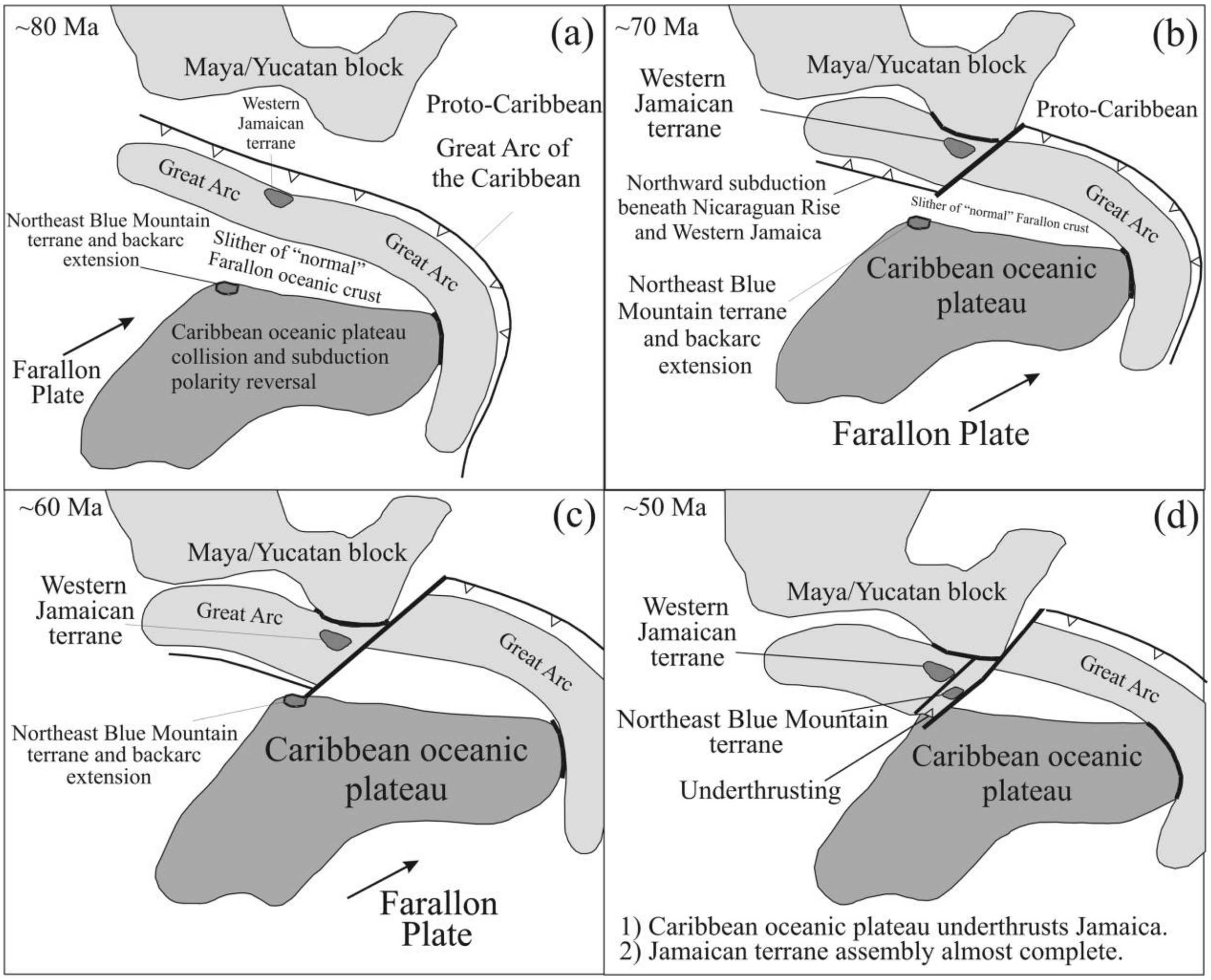


Figure 12. Illustrations showing the evolution of Jamaica in context with the Caribbean plate in the Late Cretaceous and Early Tertiary.

Caribbean oceanic crust. During the Santonian (85.8–83.5 Ma), the Caribbean oceanic plateau moved to the northeast and collided with the southern portion of the Great Arc of the Caribbean to "choke" the northeast-dipping subduction zone. As a result, southwest-dipping subduction initiated, whereby the Proto-Caribbean oceanic crust began to subduct beneath the Caribbean oceanic plateau in the south and the Farallon oceanic crust in the north (fig. 12*a*).

Importantly, a mantle plume composition is not seen in older island arc rocks, at least in the northern section of the Great Arc before the Santonian (85.8–83.5 Ma; e.g., the Devils Racecourse Formation, Jamaica [e.g., Hastie 2009; Hastie et al. 2009]), because (1) the Caribbean oceanic plateau did not begin to form until ~94 Ma and therefore could not affect the compositions of any pre-90-Ma arc rocks in the Great Arc and (2) after formation, the Caribbean oceanic plateau had to be transported to the northeast to initiate subduction reversal and be close enough to influence the composition of lavas being erupted in the Great Arc.

In the Mid- to Late Cretaceous, Jamaica formed as two separate terranes (e.g., Pindell and Kennan 2009), one formed as part of the northern Great Arc of the Caribbean and one formed on or near the Caribbean ocean plateau (fig. 12*a*, 12*b*). The former, known as the western Jamaica terrane, makes up most of what is now present-day Jamaica. It is composed of island arc lavas of the Great Arc that range in age from 135 to 80 Ma (e.g., Hastie et al. 2009, 2010). The second terrane, known as the northeast Blue Mountain terrane, formed after the Santonian (85.8–83.5 Ma) and is composed of the Mid- to Late Campanian Bellevue lavas. The northeast Blue

Mountain terrane developed after subduction reversal along the Great Arc in a back-arc region either on or close to the Caribbean oceanic plateau (fig. 12*b*, 12*c*). This explains why the lavas are derived from a mantle plume source region. As southwest subduction proceeded, the northern section of the Great Arc, which included the western Jamaica terrane, collided with the Maya/Yucatan Block (fig. 12*b*; e.g., Pindell and Dewey 1982). As the middle section of the Great Arc and the Caribbean oceanic plateau continued to be tectonically emplaced between the Americas, the northeast Blue Mountain terrane was eventually accreted to western Jamaica (fig. 12*c*, 12*d*).

In contrast, the switch from DMM to oceanic plateau mantle source components at ~75 Ma is difficult to explain with the multiple-arc model (fig. 2*c*). For example, the Caribbean oceanic plateau could not have been erupted above a southwest-directed subduction zone at ~90 Ma because the subducting plate would prevent the plume from upwelling close enough to the Great Arc (fig. 2*c*). Hastie and Kerr (2010) have also demonstrated that a slab gap cannot be responsible for allowing the mantle plume to upwell close to the Great Arc because the resultant plateau lavas would develop arclike signatures, and subduction-contaminated lavas have not been observed either in extensive accreted oceanic plateau terranes along the Caribbean margins (e.g., Kerr et al. 2003; Thompson et al. 2003; Hastie et al. 2008) or from drill sites in the interior (e.g., Révillon et al. 2000; Kerr et al. 2009).

The results of this study also pose significant problems for the Aptian/Albian reversal model of Pindell et al. (2006) and Pindell and Kennan (2009) in that the mantle plume source region of the Caribbean oceanic plateau would have to have been far enough away from the Great Arc at ~90 Ma that it did not influence the composition of the arc source region yet be subsequently transported close to the Great Arc at ~75 Ma. This transportation is difficult in the Aptian/Albian reversal model because the southwest-directed subduction beneath the Great Arc would not allow the Caribbean plateau to be transported to the northeast to interact with the Great Arc. Moreover, similar to the multiple arc model, the southwest-dipping subducted plate would prevent the plume from rising and forming the Caribbean oceanic plateau close to the arc, and as has been noted above, this cannot be resolved by invoking a slab gap (Hastie and Kerr 2010).

Furthermore, Kerr et al. (2003), Hastie (2009), and Hastie et al. (2009) demonstrated that the change in island arc composition from IAT to CA does not require a change in subduction polarity at any particular time. A change in IAT to CA composition can occur because of a variety of tectonomagmatic processes within an intraoceanic island arc, although the subduction of differing sedimentary components explains most of the IAT to CA change in chemistry (e.g., Jolly et al. 2006; Marchesi et al. 2007; Hastie 2009).

Consequently, in light of this persuasive petrological and paleontological evidence, we continue to propose that the plateau reversal model of Caribbean plate evolution best explains the geochemical changes seen in the island arc lavas of the Great Arc of the Caribbean.

Conclusions

1. The Bellevue lavas represent a Mid- to Late Campanian BAB succession of volcanic rocks. They are tholeiitic and are composed of basic/intermediate and intermediate/acidic subgroups that can be related by fractional crystallization of olivine, plagioclase feldspar, and clinopyroxene.

2. The Bellevue lavas extend the range of IAT lavas in the Caribbean region up until ~75 Ma.

3. Trace element and Hf radiogenic isotope data indicate that the mantle component of the Bellevue BAB magmas was a mantle plume source region. The Bellevue lavas are derived from 10%–20% partial melting of an oceanic plateau mantle source comprising spinel peridotite that had previously undergone approximately 5%–7.5% prior melt extraction in the garnet stability field.

4. Trace element and Nd-Hf radiogenic isotope systematics, combined with $(Ce/Ce^*)_{n\text{-}mn}$ and Th/La ratios, reveal that the Bellevue mantle source region was contaminated with an aqueous slab-related component derived from both the altered basaltic portion of the slab and its accompanying pelagic sedimentary veneer.

5. Island arc lavas on Jamaica are derived from N-MORB-like mantle source regions until ~75 Ma, when the Bellevue lavas were derived from an oceanic plateau source region. The switch in mantle source regions demonstrates that on Jamaica, the Caribbean oceanic plateau did not affect the composition of the Great Arc of the Caribbean until the Mid- to Late Campanian. Consequently, it is clear that the data presented in this paper are best explained by a late Cretaceous plateau reversal model of Caribbean plate evolution.

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